Defense Technical Information Center Compilation Part Notice

ADP010832

TITLE: ENVISAT ASAR - Design & Performance with a View to the Future

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Document partially illegible.

This paper is part of the following report:

TITLE: Space-Based Observation Technology

To order the complete compilation report, use: ADA391327

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010816 thru ADP010842

ENVISAT ASAR – Design & Performance with a View to the Future

Michael Hutchinson, Michael D. Gibbons
(Email: michael.hutchinson@astrium-space.com)
Astrium (UK) ltd.
Directorate of Science and Earth Observation & Meteorology
Anchorage Road, Anchorage Park, Portsmouth, Hampshire PO3 5PU
England

Summary: The Advanced Synthetic Aperture Radar (ASAR) is a 'C' band dual linear polarized multi-mode terrain monitoring radar forming part of the environmental satellite (ENVISAT) mission. It is to be launched on Ariane 5 in 2001. With heritage from the highly successful ERS-1 & ERS-2 SAR instruments Astrium Ltd. have developed the system design of ASAR in order to provide polarisation diversity, flexible swath selection, and wide swath techniques providing a range of operating modes with data products to suit various needs. This paper describes the overall instrument architecture summarising the key technology areas and the characteristics of each operating mode. It also reviews the major technical challenges that were faced and how they were resolved. The ASAR design based on the use of an active antenna, with individual subarray temperature compensation and internal calibration loop, is complex but a breakthrough with respect to earlier passive antenna designs. The instrument calibration scheme is described and the predicted system performance presented for key parameters based on FM test results. Budgets for mass and power are also provided. The paper concludes with a review of the future SAR development activities that are currently in progress at Astrium Ltd (formerly Matra Marconi Space (UK)).

Introduction: Following the success of the ERS 1 & 2 missions the next generation ESA environmental satellite was conceived and would include a SAR instrument. The advanced SAR (ASAR) design was developed by Matra Marconi Space (UK) with the concept of an active antenna allowing a dramatic improvement in the flexibility of SAR operation. Demonstration equipments were built and tested to confirm the technology capabilities, following which the European Space Agency adopted the design for the ENVISAT program. Subsequently a full technology program was embarked upon involving 22 sub-contractors over 11 countries. This technological step has over recent years been a major contributor to the development of a stronger European Space community.

The original ASAR instrument brief was to provide performance equivalent to or better than that of ERS, while utilising the full flexibility of the active antenna architecture to provide selectable swaths and dual polarisation. The two basic modes of ERS were to be retained, ie. Image and Wave, but swath versatility opened the possibility for increased coverage using scansar mode; and polarisation diversity. The complexity of the control system was therefore to be increased. Functionally the instrument will provide the capability of imaging a large range of incidence angles with high, medium and low spatial resolutions combined with a dual-polarisation. These features will assign to this sensor a role of primary importance for future microwave imaging requirements.

Architecture: The ASAR instrument consists of two main elements, the Central Electronics Sub-Assembly (CESA) and the Antenna Sub-Assembly (ASA). The whole being designed with a fully redundant electronics systems architecture and a life requirement of 5 years in the Low Earth Polar Orbit environment. The CESA provides control and RF signals, receive conditioning to IF and Baseband, and data processing. The ASA provides RF power generation, low noise receivers and antenna beamforming. The CESA equipments are situated on internal panel faces within the payload equipment bay of the satellite and the ASA is fitted on an angled mounting frame on the lower face of the satellite. Connection between these assemblies is achieved with the Instrument Distribution Subsystem (IDS), which includes the antenna feed waveguide (AFW). The satellite configuration is illustrated in Figure 1, which shows the orientation of the antenna lengthwise in the flight direction. The larger planar structure also depicted in Figure 1 represents the solar array.

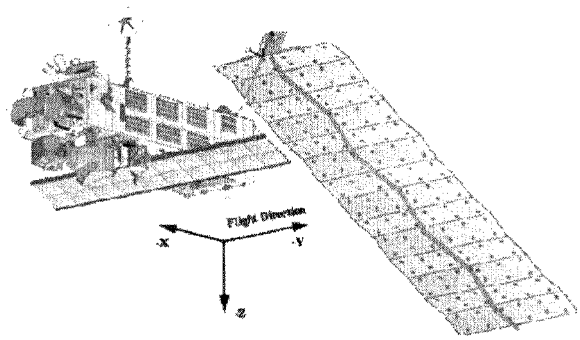

Figure 1 ENVISAT Illustration (courtesy of ESA)

The CESA hardware tree is provided in Figure 2. The instrument is interfaced to the satellite for command and control through the CSS, which comprises two cold redundant ICE units. These each contain a primary processor or CPU (central processing unit) and provide

Paper presented at the RTO SET Symposium on "Space-Based Observation Technology", held on the Island of Samos, Greece, 16-18 October 2000, and published in RTO MP-61.

the 'intelligent' interface, managing the derivation and distribution of the operational parameters (eg. transmit pulse characteristics and antenna beams among many others). It generates the instrument operation timeline and also provides routine monitoring and crisis management procedures. Command interfaces with the DSS and the TSS (part of the ASA) are provided by a MIL-STD-1553 bus. Control signals are routed via specific interfaces to manage the detailed pulse timing sequences of the radar.

The instrument transmit pulse characteristics are flexibly derived within the DSS based on parameters sent from the CSS. The output of the DSS is an up-chirp pulse centred at the IF carrier frequency (124 MHz). Within the RFSS this pulse is up-converted to the main transmission frequency (5.331 GHz) and amplified to provide the correct input power to the antenna.

In receive the RF echo signal from the ASA is delivered to the RFSS where it is filtered, amplified and downconverted again to IF. The receive gain of the RFSS can be commanded to optimise the signal levels over the ADC dynamic range. The received IF signal is passed to the DSS where it is coherently demodulated into In-phase & Quadrature (I & Q) components, which are passed through separate anti-alias filters and digitised using 8-bit A/D converters.

CESA
- RF Subsystem (RFSS)
  - RF Equipment A (RFEA)
  - RF Equipment B (RFEB)
  - Calibration Switch Equipment (CSE)
- Data Subsystem (DSS)
  - Data Equipment A (DEA)
  - Data Equipment B (DEB)
  - Cross Strap Assembly (CSA)
- Control Subsystem (CSS)
  - Inst. Control Equipment A (ICEA)
  - Inst. Control Equipment B (ICEB)
- Power Subsystem (PSS)
  - Power Conditioning Unit (PCU)

Figure 2 CESA Hardware Tree

Data compression is applied to the raw science data to reduce the data stream volume. This compression is performed using an FBAQ[1] (flexible block adaptive quantiser) that permits acceptable date rates with minimal degradation in image quality. It is achieved by using an algorithm optimised to the statistics of the radar signal, and implemented within an ASIC. It can be operated in three modes: Averaging (compressed), sign & magnitude (3 lsb) or Bypass (full 8-bit) depending on the type of data to be processed. The available compression ratios are 8/4, 8/3 and 8/2 bits depending on mode requirements. For the three on-board signal types to be digitised the default BAQ settings are as in Table 1.

As these functions and the general operation of the instrument results in varying internal data rates the DE also contains a pair of swap memory banks for the Science Data to be stored. Header information including on-board time and other information required by the ground processor is included with the compressed science data to form packets that are passed to the spacecraft interface.

Signal type	BAQ mode
Calibration pulse	Bypass
Noise samples	Sign/Magnitude
Echo (Signal + Noise)	Compressed 8/4 (8/2 Wave)

Table 1 BAQ Default Settings

The ASA provides the ASAR antenna, which is itself a significant feature and covered in detail within a separate paper[2]. This is an active phased array antenna 1.3m x 10m comprising five 1.3m x 2m panels which are folded into a stack position for launch. It consists of a support and services structure carrying 20 tile equipments. Each panel houses four 0.65m x 1m tiles mounted in a lattice beam structure. The ASA hardware tree is provided in Figure 3.

ASA
- Tile Subsystem x 20 (TSS)
  - Power Supply Unit x 4 (PSU)
  - Tile Control Interface Unit (TCIU)
  - Transmit Receive Module x 16 (TRM)
  - Radiator Panel (RP)
  - Corporate Feed Network x 2 (CFN)
- Antenna Support Subsystem (ASS)
  - Antenna Mounting Structure (AMS)
  - RF Panel Feed x 2 (RFPF)
  - Deployment Control Unit (DCU)
  - Deployment Motors x 4 (DEM)
  - Hold Down & Release Mechanism x 4 (HRM)
- Antenna Power Subsystem (APSS)
  - Antenna Power Switching and Monitoring Unit (APSM)

Figure 3 ASA Hardware Tree

The ASS provides the mechanical structure with five rigid Carbon Fibre Reinforced Plastic (CFRP) frames, hold-down and release, and deployment mechanisms (motors and latches). It also includes two RF distribution networks of CFRP waveguide running in parallel along the five panels to provide RF distribution for Radar and calibration signals.

In the launch configuration, the four deployable panels are folded over the fixed central panel and held together in compression by eight Hold-Down and Release Mechanisms (HRM). Each HRM consists of a retractable telescopic tube that is lever locked and tensioned in place by a kevlar cable assembly. Release is achieved using a thermal knife within each HRM that acts on the kevlar cable. Following release the panels

are deployed under the control of a Deployment Control Unit (DCU). Each of four stepper motors are activated in sequence to complete the deployment, which takes typically 1½ hours. Latching is achieved by using eight spring-loaded units built into the main longitudinal beams. When latched the structure achieves a high degree of rigidity and a planarity of better than ±4mm over the full length.

Each TSS has 16 subarrays of radiating elements with each element being connected to a TRM. The TRM contains two TR chains to provide dual polarisation (V & H). These are internally switched according to the setting provided with the beam data. The TRM achieves phase and gain controls for beam steering as well as power amplification in transmit and low-noise reception. An ASIC handles the beam data and routes the internal RF signals accordingly, also setting the appropriate commands to the phase and gain control elements. The active circuits for transmit and receive are only powered during the period of transmission or reception respectively. The TRM phase and gain settings are updated by the TCIU at least twice each PRI to facilitate transmit and receive beams. Beam data is uploaded to the TCIU from the CSS prior to the start of the mode and includes data for all the mode swaths. Swath selection is carried out during the mode by command from the CSS. The TCIU provides feed-forward temperature compensation of the TR module characteristics to provide continual high performance beamforming. This is based on TRM temperature and a set of characterisation coefficients determined during on-ground test.

The radiator panel provides the TSS structure and supports on one side 16 subarrays, each comprising 24 dual-polarised low-loss radiating elements. The TSS equipments are mounted on the other side and the TRM are connected to respective subarrays through the panel using semi-flexible coaxial cable. The cable is fixed to the subarrays at one end and a blindmate connector at the interface with the TRM. A loop is included in the cable to take up mechanical deviations during assembly, vibration and thermal environments. Separate connections are provided for the two polarisations.

Transmit pulses are received from the signal RFPF, which provides a nominally co-time equi-amplitude signal to each of the twenty TSS. Within the TSS this signal is distributed to each of sixteen TRM by the microstrip corporate feed network and passed to the radiators. Receive signals pass through a reciprocal path although the internal routing of the TRM is obviously different. Calibration signals can be injected or coupled out at a point between the TRM circulator and the radiator interface. The calibration interfaces are distributed through a corporate feed network and RFPF that are separate from the signal feeds but virtually identical in design.

The APSM distributes the spacecraft antenna power bus to each of eighty tile PSU, providing individual switch-on, over-current protection, current and status monitoring facilities for each PSU. All PSU are switched on in sequence with a delay no less than 200ms. In the event of over-current the supply to all PSU on the same tile will be disabled automatically. Status and current monitoring data is sent to the CSS for comparison with expected limits and telemetry purposes.

Calibration is an essential part of the process of accurately translating the instrument output data into absolute units of radar cross-section. Design of calibration techniques therefore form an important aspect of the instrument design, impacting the hardware and operational timeline. The science data from the instrument is a series of digital numbers related to the amplitude and phase of the received echo signal. Figure 4 illustrates the processes involved in providing a calibrated data product from the raw echo data.

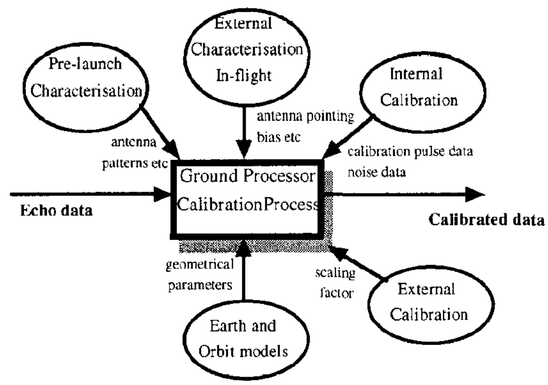

Figure 4. Calibration Data Flow

The ASAR modes are identified in Table 2 along with the associated antenna swaths used. With modes (a) to (d) the instrument is in either vertical or horizontal polarisation so there are 55 distinct mode-swath-polarisation combinations, which each need to be calibrated. Further information on ASAR modes of operation and calibration can be found in ref. 3.

Mode	Swath								Pol
	SS1	IS1	IS2	IS3	IS4	IS5	IS6	IS7	
a) Image		x	x	x	x	x	x	x	V,H
b) Wide Swath	x			x	x	x	x		V,H
d) Wave		x	x	x	x	x	x	x	V,H
c) Global Monitoring	x			x	x	x	x		V,H
e) Alternating Polarisation		x	x	x	x	x	x	x	-

Table 2 ASAR Mode / Swath Combinations

The basic requirement for instrument calibration system is to form an accurate reference, which is achieved using a target of known radar cross-section (RCS), and to monitor changes in the combined transfer function of the transmit and receive paths. These processes are separately termed external and internal calibration.

External calibration for ASAR will be carried out using three ground transponders each with an equivalent calibrated cross-section of 58 dBm^2. These are arranged to be visible simultaneously within a single swath, and are viewed over several passes. The procedure will be

repeated no more frequently than once every six months.

The 55 individual mode/swath/polarisation states that need to be calibrated could, in principle be individually calibrated at one point in the orbit. This is not necessary because parts of the system are common to a number of mode/swath/polarisation states. External calibration will therefore primarily be performed in image mode with observations made over all swaths and both polarisation states.

Other modes use mostly the same swaths and the same paths through the instrument as image mode. The exceptions are wide swath mode and global monitoring mode, which operationally represent a significant departure from image or wave modes. Both modes have a similar principal of operation and utilise one different swath to all the others therefore it is expedient to include external calibration in wide swath mode. Hence the external calibration activity is confined to image and wide swath modes with effects in other modes taken into account by on-ground characterisation.

The external calibration process is subject to errors in both the instrument and the transponder and these limit the accuracy of the calibration. Also the calibration is only strictly valid for the specific operational parameters at that time. To achieve stability around orbit and calibration over the full swath width, and for the full period between external calibrations requires further techniques.

Internal calibration allows estimation of drifts in the instrument transfer function using calibration paths within the instrument. This is repeatedly carried out in each instrument mode continually throughout the life of the instrument. Noise measurements are also made periodically to allow correction of the power level of the raw instrument data.

The precise details of operation depend on the mode being used, but essentially the technique is common to each one. The aim is to characterise the central electronics gain drift and that of the active part of the antenna on a row by row basis for both transmit and receive using special calibration pulses and the calibration loop. The ground processor uses the measured amplitude and phase of the calibration pulses from each row of TR modules to estimate the instrument gain at a single reference point in the swath.

Figure 5 illustrates the calibration paths and shows that each TR module is connected independently by signal distribution networks and a coupled point close to the radiating element. Overall the distribution network and calibration hardware provide 640 paths from the modules to a single connection at the central electronics. These distribution paths are purely passive and are designed to be equi-time delay.

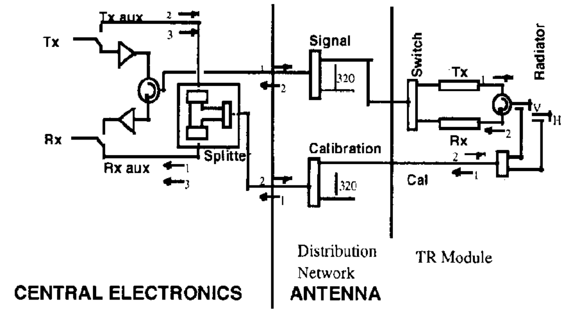

Figure 5. The Three Calibration Paths

The calibration loop around the antenna, along with the flexibility of the control system allows in-orbit monitoring of each TR module transmit and receive path, either individually or in groups. Monitoring and optimisation of the antenna performance throughout the mission is therefore possible. The loop also provides the facility to record an accurate replica of the transmitted chirp pulse waveform, which can be used for processing the SAR data. Hence, although it adds complexity and mass to the antenna the advantages are significant.

Calibration signals are routed from the auxiliary transmit path and into the auxiliary receive path through switches and a stable coupling network. The network consists of three hybrid splitters, which form a basic three way splitter with additional ports to accommodate redundancy. There are three calibration paths employed. Two of these pass through the antenna - path 1 for transmit and path 2 for receive, whereas path 3 is directed within the central RF electronics only. These are identified in Figure 5 where the path numbers are also used to identify the calibration pulses themselves.

Acquisition of the calibration pulses is carried out within different PRI during the instrument timeline and with minimal disturbance to the instrument measurement sequence. The pulses are digitized and sent to the ground processor along with the normal echo data. The Image mode timeline is summarised in Figure 6 to illustrate the typical calibration sequencing although this is not specific of all the modes.

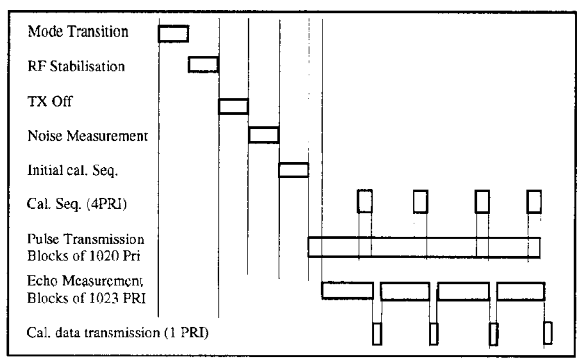

Figure 6 Image Mode Summary Timeline

The internal calibration procedure is carried out for all 32 rows of the antenna array in succession. Following initial calibration, the echo measurement within the mode commences. Continuous echo measurements are taken, interspersed with a periodic calibration sequence every 1024 PRI. Each periodic calibration calibrates a single antenna row, and although the sequence occupies four PRI, only one echo is corrupted due to the routing and timing of pulses. The periodic calibration serves to track changes relative to the initial calibration. In the ground processor the 32 calibration data sets for each of transmit and receive, are used to estimate the overall gain of the instrument (transmit and receive paths) at a reference elevation angle corresponding to a reference point within the swath. In most cases all calibration pulses are representative chirp signals, the exception is in Wave mode where because of data rate limitations the initial calibration is performed with CW pulses. This is valid for tracking gain variations, with replicas being generated from periodic calibration pulses.

External characterisation establishes certain in-orbit parameters where the conditions cannot be fully represented on-ground, e.g. deployment and zero-g effects. It involves measuring the transmitted amplitude and phase from each antenna row both directly using an on-ground receiver, and through the instrument using the calibration path and processed data output. In the context of calibration this procedure provides a relative measure of the on-board calibration signals with respect to the transmitted signals, and is used to correct the antenna calibration data. The direct on-ground measurement of each of the 32 row signals also serves to determine antenna elevation pointing errors by using relative phase information. The procedure aims to track changes in that part of the antenna that lies outside the calibration loop, and also in the calibration loop itself. External characterisation is performed using a dedicated instrument mode and will be carried out at nominally six month intervals throughout the lifetime of the instrument.

Instrument Imaging Modes: ASAR will exploit its flexibility through various operational modes. To enable the Instrument to provide these modes the on-board software and control architecture has to facilitate the complex timeline to provide swath selection along with measurements of target, calibration pulses and noise samples. Figure 1 illustrates the concept of the different operating modes and summarises the data product available in each case.

Image Mode generates high spatial resolution data products (30m) downloaded over the Satellite high rate science data link. The scanned area being selected from a total of seven available swaths located over a range of incidence angles spanning 15° to 45°. Typically this mode is expected to be used in 10 minute periods over less than 1/3rd of the orbit due to the high data rate and relatively high power with resulting thermal profile.

Imaging is performed by transmitting a continuous series of pulses and receiving the echo information from regions on the ground. The coverage regions are defined firstly by the antenna swath and secondly by the exact placement of the receive period within the pulse repetition interval (PRI).

Wave Mode generates vignettes of nominally 5km by 5km and spaced at 100 km intervals along-track with high spatial resolution (30m). The mode is effectively a segmented Image mode with alternating swath regions. The position of the vignettes can be selected to alternate between any two of the seven swaths as defined for Image mode. This mode offers a low data rate typically being used as part of a mode sequence around orbit, and specifically intended to monitor oceanic regions. The quiescent period between vignettes is used to transfer data to the data management system via the low rate data interface. Due to the relatively benign power requirements and thermal dissipation this mode may be of any defined duration.

Wide Swath Mode provides a 400km medium resolution (150m) ScanSAR product covering five sub-swaths over the nominal 15° to 45° angle of incidence and providing data over the High Rate data link. The instrument utilises a scan-SAR sequence that repeats after 5 subswaths, although the instrument capability is for 14.

Global Monitoring Mode is also based on the ScanSAR technique using five sub-swaths as for wide swath mode. This mode offers a low data rate wide swath products over 400 km ground range with spatial resolution of 1000 m.

Each of the above modes are typically operated in either of two orthogonal polarisations; HH (horizontal transmit, horizontal receive) or VV (vertical transmit, vertical receive). In contrast the **Alternating Polarisation Mode** provides two simultaneous images by application of interleaved sub-swath operation from the same area in HH and VV polarisations, HH and HV or VV and VH, with the same imaging geometry and resolution as Image Mode. Imaging is performed in any single swath as for Image mode, effectively utilising the ScanSAR technique but without varying subswath.

In-orbit performance parameters are not available through direct on-ground measurement, they have to be computed using a suite of algorithms and various inputs. The input parameters are either assumptions (eg. related to the earth model, ground processor operation, atmospheric characteristics) or characteristics of the instrument determined by analysis or test (eg. noise figure, temperature, thermal sensitivity, antenna patterns). Early performance predictions relied heavily on analytically derived instrument characteristics which necessarily included margin by virtue of either the values used or assumptions made in the analysis. These have since been replaced by direct measurement of the hardware where possible, although some inputs to the performance algorithms remain calculated from low level test data when direct measurement of the CESA, ASA or instrument is impractical. Figure 7 provides a list of all the major ASAR specification parameters and the range of values achieved across all swaths for each mode, using the flight model input data.

Parameter	Unit	Image	Alternating Polarisation	Wide Swath	Global Monitoring	Wave
Polarisation	-	VV or HH		VV or HH	VV or HH	VV or HH
Spatial Resolution (Az., El.)	m					
Near swath (IS1)		27.5, 37.6	28.7, 37.6	N/A	N/A	27.5, 37.6
Other Swaths		27.4, 29.6	28.6, 29.6	149.2, 145.7	942.3, 977.2	27.4, 29.6
Radiometric Resolution	dB	1.54	2.46 to 2.50	1.45 to 1.72	1.34 to 1.38	1.54
Point Target Ambiguity Ratio	dB					
Azimuth		25.9 to 29.7	25.9 to 29.7	22.2 to 28.3	26.6 to 29.5	25.8 to 29.7
Range		31.5 to 47.0	26.4 to 41.9	24.9 to 32.2	25.0 to 32.3	31.5 to 47.0
Dist. Target Ambiguity Ratio	dB					
Azimuth		22.6 to 24.7	18.1 to 24.6	20.3 to 35.0	24.3 to 27.3	22.6 to 24.7
Range		17.0 to 40.2	17.0 to 40.2	17.0 to 31.5	17.0 to 31.5	21.2 to 48.6
Radiometric Stability (1σ)	dB	0.33 to 0.43	0.50 to 0.58	0.34 to 0.46	0.46 to 0.56	0.57 to 0.67
Radiometric Accuracy (3σ)	dB	1.18 to 1.48	1.81 to 2.14	1.21 to 1.56	1.54 to 1.82	1.83 to 2.14
Noise Equivalent σ_o	dB	-18.9 to -21.3	-18.6 to -21.2	-19.8 to -25.5	-30.1 to -34.0	-18.7 to -21.6
Noise Equivalent σ_0 margin	dB	-1.0 to 6.0	-1.3 to 6.0	3.62 to 6.93	10.8 to 17.4	-0.7 to 17.0
Incidence Angle	deg	15 to 45	15 to 45	17 to 43	17 to 43	15 to 45
Swath width (quantity swaths)	km	103 to 58 (7)	103 to 58 (7)	406 (5)	406 (5)	5 (7)
Localisation Accuracy	m					
Azimuth		70.7 to 75.6	70.7 to 75.6	71.1 to 74.9	71.1 to 74.9	70.7 to 75.6
Range		48.7 to 125.0	48.7 to 125.0	52.5 to 111.5	55.6 to 112.9	48.7 to 125.0
DC Power (Mean)	W	1358	1358	1195	640	555
Data Rate (Peak)	Mb/s	95.8	95.8	95.8	0.58	0.89

Figure 7: ASAR Performance Summary

Two of the key swath dependant parameters are distributed range ambiguity ratio and noise-equivalent sigma-nought. These have been plotted for all swaths in Image mode showing their variation over the full coverage region in Figure 8.

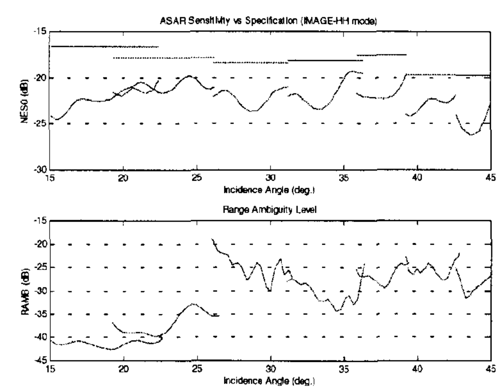

Figure 8: Sensitivity & Range Ambiguity

Notice that Figure 7 also provides NESO margin with respect to the mid-swath surface model as this is the specified parameter

Notable Design Features of ASAR: Within the CESA a high degree of command robustness and independence has been built into the Control Sub-system (CSS) and the secondary processors of the Data Subsystem (DSS) and the Tile TCIU. Within the CSS the reception of Macro Commands from the ground are not only verified to eliminate corruption but are also checked for consistency of the data encoded and the compatibility of the command to the current operational mode. The CSS also holds default parameter settings for optimised performance, which are initialised on power-up. These settings may also be modified by ground command and retained in RAM (random access memory). The benefits of this approach are that the time from initial power up to normal operation is minimised and the telecommand budget is severely reduced.

Through digital chirp generation the CESA is able to provide signal characteristics matched precisely to the required swath, both in terms of pulse duration and bandwidth. This efficiently facilitates the various needs associated with the variety of available operating modes of the instrument. Along with the many other comandable features this also allows for re-optimisation of performance during the instrument lifetime, or when a new operational scenario is envisaged.

Budgets: The instrument mass and power budgets are summarised for the main subassemblies in Table and Table respectively.

Item	Mass (Kg)
ASA (Structure)	239
ASA (TSS)	327
ASA (APSM)	17
ASA (Deployment, HRM, Harness)	155
CESA	58
IDS	20
Total Mass (Kg)	817

Table 3 Instrument Mass Budget

	Mode				
	Image	Wide Swath	Wave	Global Monitoring	Alternating Polarisation
Pulse Duty Cycle (%)	4.47	3.52	5.68	4.41	4.47
CESA (Watts)	131	131	131	131	131
ASA (Watts)	1234	1060	388	472	1234
Total (Watts)	1365	1191	519	603	1365

Table 4 Instrument Power Budget

Key technology areas: The development of the ASAR required a number of Technology developments to be completed to enable the performance of the instrument to be met. These were focussed in the components of the Data sub-system and in the Tile sub-system. The Data sub-system development required the procurement and incorporation of suitable components for the FBAQ and the digital chirp generator. These technologies were however at an appropriate degree of advancement at the time of design and a space qualifiable set of components were developed with less than the expected impact.

The Tile sub-system design and qualification was however more complex requiring the development of new processes as well as new ASIC, MMIC and hybrid components. The main endeavour centred on the Radiator and TR module development. Although the TR module architecture was established early on following development work at Astrium Ltd., the implementation of a qualified design proved to be difficult. These issues are addressed in a dedicated paper[2].

Challenges met during development: Aside from the technology development issues one of the more spectacular challenges in the ASAR design has been the development of the Antenna structure. Although not new technologically, the stowed panel design and deployment requirements to meet stringent planarity specifications have required interesting solutions to the problems of both design and handling. Designed for use in a zero-g environment the deployment hinges and motors are relatively delicate components, the stepper

motors having a low operating torque (80Newtons max). The demonstration of deployment and verification of compliance to the required antenna performance therefore demanded development of some ingenious devices. A deployment gantry with a variable geometry, which allowed the panels to be stowed and unfolded with near zero torque was one of the solutions. The further development of a 'zero-g' deployment test room where the Antenna is deployed in the horizontal plane supported on air bearings was a further challenge. This facility required construction of a resin floor some 14m x 5m having less than 1mm distortion in flatness. A factor in achieving this, related to the Portsmouth site location required the resin to be poured and set at the ebb of the tide!.

More generally though, technology developments created many challenges over the eight year development programme. To mitigate some of the risks posed by such development on those features that were characterisable in terms of performance, the system design was structured to allow software control of as many parameters affecting performance as possible. Thus tables of control parameters for such functionalities as the BAQ algorithms, beam steering, and tile characterisation coefficients have been not only stored in data tables but can also be easily modified by ground control. Furthermore chirp pre-distortion coefficients are made more accessible through being included within the mode 'set-characteristics' commands. This design approach in conjunction with calibration techniques was taken to allow for the optimisation of performance at any phase of design and use.

Given this built-in flexibility, the on-board software was several orders of magnitude more complex than previous designs, particularly with the need to minimise ground telemetry / telecommand budgets. This in itself formed a significant challenge, and in order to achieve a realistic schedule required the recognition that the effort and cost of software design had finally surpassed that of the hardware in which it was to be embedded. Due to schedule constraints and the unmeasured characteristics of the integrated instrument at software build date, the flexibility of the software was retained until the last minute by use of EEPROM. These are being replaced by PROM only just prior to final satellite integration acceptance test, since at the time of design EEPROMS were not available for space qualified use. Complexity of the software design was thus justified by the need to re-optimise the mode characteristics following resolution of the more major system design challenges.

Now having faced these major development undertakings in hardware, software and AIT the ASAR instrument has finally emerged as a successful and powerful instrument. It is currently at an advanced stage of integration with the ENVISAT spacecraft at ESTEC, which is depicted in Figure 9. Here the stowed antenna is clearly visible without MLI showing some of the harness and RFPF network.

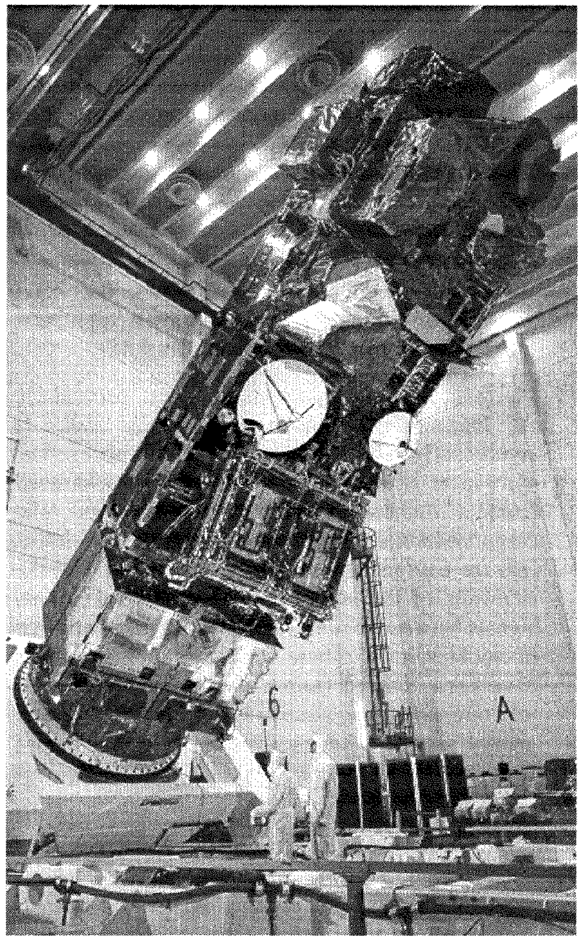

Figure 9 ENVISAT-1 Flight Model (courtesy of ESA)

Lessons learned and Further Developments: The design of the ASAR instrument, as of the ERS AMI before it, is a major step forward in the development of spaceborne SAR. Lessons learnt during both programmes have been exploited at Astrium Ltd.. In definition of the **CORE** (Common Radar Elements) development programme it is intended to form a flexible, adaptable SAR for use at frequencies from L to K band, and for integration into a number of platforms, including airborne vehicles. The **CRESS** (Core Radar Electronic Subsystem) has now been adopted as the Sensor Electronics for the SAR payload for the RADARSAT-2 programme. Examples of the enhancements introduced as a result of the ASAR experience are outlined below:

- Chirp predistortion was found to be a useful facility on ASAR. To improve the flexibility of the system further Core has adopted to store the waveform in memory to be uploadable by command as required.
- Both ASAR and ERS-1/2 AMI used the same IF frequency for Transmit and Receive. For Core different IF are used to ease isolation between transmit and receive.

- Block Adaptive Quantisation is used by Core, as for ASAR. However the algorithm has been refined and the faster technology has been adopted.
- The internal control bus used by Core is the CAN bus. This is used widely within the automotive industry, but has been flown by SSTL, and can be made with space qualified processes. The bus is used for collection of telemetry, saving harness mass and reducing routing problems. The CAN also has advantage in that it overcomes the 1553 problems of limited number of terminals, high mass transformer coupling and limited data fields.
- Mechanical construction of the Core, particularly the Intermediate Frequency Equipment (IFE) is significantly different from the ASAR boxes. The Core ideal is to enable a system to be constructed from a number of modular components. The components are the modules, which can be slotted into the equipment box. In the case of the IFE the sidewalls of the equipment are used to distribute signals between modules in order to reduce external interconnections. These construction techniques have been adopted from a number of commercial telecommunication satellite programmes and greatly simplify the manufacture of a number of Core-based systems.

This list is not exhaustive, and where appropriate the heritage of ASAR and its successful predecessors has been maintained. However, the Core/RADARSAT-2 systems will offer performance improvements over ERS AMI and ASAR, with significantly greater flexibility and adaptability, depending on the mission.

The **FESS** (Front-end Electronics Subsystem) includes the antenna radiators, RF distribution and power amplification. Architectures range from single polarized slotted waveguide fed by microwave power modules, to muti-polar integrated TR module and radiator structures, in many ways similar in concept to the ASAR antenna. Current work at Astrium Ltd. includes development of a generic TR module architecture to form a building block for multi-frequency, multi-polar applications. Future concepts that include higher levels of integration between the TR module elements, power and control distribution, radiating elements and structure are also being actively studied[4].

The complexity of the ASAR antenna structure and deployment requirements has been a major impetus for the pursuit of a more efficient SAR spacecraft architecture. To this end Astrium Ltd. have patented a novel platform designated 'Snapdragon', which maximises utilisation of the launch vehicle payload volume and incorporates a large planar antenna with only one deployment hingeline. The design[5] can be scaled according to launcher constraints and with current launcher capabilities allows antenna areas in the range $11.7m^2$ to $80m^2$ for the basic configuration. Larger areas can be incorporated by additional deployable sections.

Conclusion: ASAR has faced many challenges both expected and unexpected, as could be anticipated with new technology applications. The major achievement has been to triumph over each one and thereby push forward the technology of the European space industry. Lessons learned are already benefiting new product developments and projects with the Core technology now forming the building blocks of the next generation of space-borne and air-borne equipments. Examples have been provided to show how the design and manufacturabiliy of SAR systems has been improved and embodied in the Core Radar programme. Investment in this development is now reaping rewards with Core being adopted for missions such as the RADARSAT-2 Sensor Electronics.

The Astrium organisation is a new European company formed between two of the most significant contributors to the ENVISAT/ASAR programme and is able to call on all the extensive experience gained. Although there is no direct follow-on SAR program from ESA, industry is now in a position to take the technology forward.

Acknowledgements:
The authors acknowledge the work of colleagues in Astrium Ltd., Alcatel Espace, Alenia Spazio and many other subcontracting organisations in development of the ASAR Instrument. Also the support provided by Astrium GMBH and the ESA Technology Centre (ESTEC) as mission prime contractor and customer respectively.

References:

1. D.L.Hurd, G.Fowler, Optimisation of the ASAR Block Adaptive Quantisation Scheme, EUSAR '96, Königswinter, Germany 1996.
2. M.D.Gibbons, R.Tucker, Design & Performance of an Active Phased Array Antenna for the ENVISAT ASAR, NATO RTA Sensors & Technology Panel symposium on space based observation technology, Samos, Greece, 16-18 October 2000.
3. S.S.Hartley, M.D.Gibbons, ASAR – Calibration Aspects for a Multi-Mode Instrument, CEOS SAR Workshop 3-6 February 1998.
4. M.A.B.Cohen et al., Integrated Front End Subsystem Design Concept for Future Spaceborne SAR, EUSAR 2000, Munich, 23-25 May 2000
5. J.D.McCaughey et al., Instrument Carrier – SAR specific Polymorphic Configuration, EUSAR '98, Friedrichshafen, Germany, May 1998.